Recent Charm Production and Neutrino Oscillation Results From the CHORUS Experiment

A. KAYIS-TOPAKSU*

Çukurova University, Adana, Turkey, Aysel.Kayis@cern.ch

** for the CHORUS collaboration*

Abstract. CHORUS Experiment was taking data during the years of 1994-1997. In total about 100 000 charged-current(CC) neutrino interactions were located in the nuclear emulsion target and fully reconstructed. In addition to the oscillation search, measurements of charm production have been also performed. From the sample of 100 000 events based on the data acquired by new automatic scanning system, 2013 charm-decay events were selected by a pattern recognition program. A comprehensive study of charm production by neutrinos being made. We report here some of the recent results on charm production and neutrino oscillation results.

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CHORUS EXPERİMENT

The primary aim of the CHORUS experiment is to search for $\nu_\mu \rightarrow \nu_\tau$ oscillation by detecting the characteristic decay topology of the τ lepton produced in ν_τ CC interaction. The apparatus was exposed to the CERN SPS wide-band neutrino beam during the years 1994-1997. The accumulated neutrino interactions in the emulsion were analysed by fully automatic scanning systems. Since charmed particles have a lifetime similar to that of the τ lepton, the experiment is also very well suited to study charm production. The CHORUS [1] detector is a hybrid setup which combines a nuclear emulsion target with various electronic detectors such as trigger hodoscopes, a scintillating fibre tracker system, an air core magnet, electromagnetic and hadronic calorimeters and a muon spectrometer. The emulsion target has an overall mass of 770 kg and is segmented into four stacks. The emulsion scanning has been performed by fully automatic microscopes equipped with CCD cameras and a read out system, called Track Selector [2].

Results on Charm Production

The improvements in the automatic emulsion scanning systems allowed us to perform large-volume data-taking around neutrino interactions located in the emulsion target. Thanks to the sub-micron spatial resolution of the emulsion, production of charmed particles in neutrino interactions followed by their decay can be fully observed. Therefore it is possible to perform a topological identification of charmed hadron decays which reduces the background to a very low level. The CHORUS experiment collected more than 2000 neutrino interactions with a charmed particle. In CHORUS, measurements of the production rate of D^0 and D^{*+} mesons were performed based on 100 000 CC neutrino interactions which were located in the nuclear emulsion target and fully reconstructed. From this sample of events, 1048 CC neutrino interactions with a D^0 in the final state were selected and confirmed as neutral-particle decays through visual inspection. The ratio of decay branching fractions of the D^0 into four charged particles (V4) to two charged particles (V2) was measured to be $B(D^0 \to V4)/B(D^0 \to V2) = 0.207 \pm 0.0106(stat) \pm 0.004(syst)$. The inclusive measurement of the observed production rate of the D^0 with a decay into four charged prongs in combination with external measurements of this topological branching ratio was used to determine the total D^0 production rate by neutrinos without additional assumption on the branching fractions. The value of D^0 production rate relative to the CC cross-section was found to be $\sigma(D^0)/\sigma(CC) = 0.0269 \pm 0.0018(stat) \pm 0.0013(syst)$. In addition, the same normalization method was used to deduce the inclusive topological decay rate into final states with neutral particles only. A value for this branching ratio $B(D^0 \to V0) = 0.218 \pm 0.049(stat) \pm 0.036(syst)$ was found [3].

Based on the same charm statistics, the effective branching ratio of charmed particles into muons was determined to be $\overline{B}_\mu = [7.3 \pm 0.8(stat) \pm 0.2(syst)]\%$ [4]. In a similar manner, one can obtain dimuon cross-section normalized to the CC cross-section. The value of $[3.16 \pm 0.34(stat) \pm 0.09(syst)] \times 10^{-3}$ was found for this ratio.

Since already a high-statistics sample of neutrino interactions with a D^0 in the final state was collected, a production cross-section measurement of D^{*+} in neutrino-nucleon CC interactions was performed using the decay mode of $D^{*+} \to D^0 \partial^+$. The low Q-value of the decay was used to isolate a sample of candidate events containing a positive hadron with a small p_T with respect to the D^0 direction. A signal of 22.1±5.5 D^{*+} events was obtained[5]. A production cross-section of D^{*+} relative to D^0 production cross section, $\sigma(D^{*+})/\sigma(D^0) = 0.38 \pm 0.09(stat) \pm 0.05(syst)$ was measured.

The measurement of the fragmentation properties of charmed particle production gives insight in the hadronization process and allows a better description of charm production. In the CHORUS experiment the momentum of D^0 required to obtain *z,* which is defined as the fraction of the total hadronic jet energy carried by the charmed meson, cannot be directly measured. Instead, one can exploit the correlation between the momentum and the angular distribution of the decay product. Although the correlation is clear, no precise measurement of charm momentum can be obtained on an event by event basis. Therefore, the momentum spectrum is obtained statistically from the average emission angle of the decay daughters making use of an unfolding procedure. The mean value of z was found to be $z = 0.63 \pm 0.03(stat) \pm 0.01(syst)$ [6]. From the fit to the formula of Peterson et al. [7], a value for the Peterson parameter $\varepsilon_p = 0.108 \pm 0.017(\text{stat}) \pm 0.013(\text{syst})$ was found. The fit to the data using the Collins-Spiller [8] approach gave a value for the fit parameter $\varepsilon_{cs} = 0.21^{+0.05}_{-0.041} \pm 0.04$. Some other fragmentation variables like Feynman x (x_F) and the transverse angle ($\tan\vartheta^{out}$) out of the leptonic plane defined by the muon and the neutrino were also measured. The average value of $x_F = 0.38 \pm 0.04(\text{stat}) \pm 0.03(\text{syst})$ is found for x_F. The distribution of $\tan\vartheta^{out}$ was measured with an average value $\tan\theta^{out} = 0.030 \pm 0.002$.

A systematic search for superfragments has been performed in 22 200 neutrino-emulsion interactions. The absence of candidates provides an upper limit for the superfragment production rate of 1.9×10^{-4}(90%C.L) relative to neutrino CC interactions at an average neutrino energy of 27 GeV. In the same analysis 28 hyperfragment decays were found. For the first time, a production rate of hyperfragments in neutrino-emulsion interactions was obtained. The value of the hyperfragment production rate relative to the neutrino CC cross-section was found to be $(2.0 \pm 0.4(\text{stat}) \pm 0.3(\text{syst})) \times 10^{-3}$.

Results on Neutrino Oscillation

The search for ν_τ interactions is performed for both leptonic and hadronic decays of the τ lepton. Both decay modes give rise in the emulsion to a kink toplogy: a track from the neutrino interaction showing a change of direction after a short path. The analysis is done separating two classes of events: one with a negative muon and the other sample with no muon in the event and a negatively charged hadron. The negatively charged muons and hadrons are followed into the emulsion stack and a kink topology near to the interaction vertex is used to define a decay topology. Cuts on the decay angle and transverse momentum to reject background due to kaon decays and hadronic interactions are applied. A cut on the azimuthal angle between τ candidate and hadronic system is also applied to reject the background from charm production and hadronic interactions on the sample without muon. This analysis excludes a region of the $\nu_\mu \rightarrow \nu_\tau$ oscillation with $\sin^2 2\theta > 3.36 \times 10^{-4}$ (at 90% CL) at high Δm^2 and $\Delta m^2 > 0.5 e\text{V}^2 / c^4$ at $\sin^2 2\theta = 1$ with a oscillation probability of $P_{osc}(\nu_\mu \rightarrow \nu_\tau) < 1.68 \times 10^{-4}$.

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